Acta Polytechnica CTU Proceedings **45**:66–69, 2023
https://doi.org/10.14311/APP.2023.45.0066

Published by the Czech Technical University in Prague

EARTH STRUCTURES – A SUMMARY OF THE LAST 50 YEARS

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Abstract. This paper discusses changes and developments in the field of Earth Structures that have been presented and discussed over the last fifty years at the annual national conferences on Foundation Engineering held (with foreign participation) in the city of Brno.

Keywords: Earth structures, hydro engineering, environmental engineering.

1. Introduction

The modern view of the construction of earth structures in the Czech Republic began in the late 1930s. After a certain pause, the situation took to new tracks in the 1960s and connected with the beginning of the traditional regular staging of the Foundation Engineering Brno conferences. The paper first summarizes the decisive steps in the field of soil mechanics applicable in general. From the point of view of various earth structures, attention is focused on earth structures of transport, hydro and environmental structures. The emphasis is mainly on the most common problems with which these constructions are connected.

The development of soil mechanics in the Czech Republic can be associated with the end of the 1930s, when the then Dr. Ing. A. Myslivec returned from an internship abroad in Holland, and was dedicated to the development of soil mechanics in its theoretical domain, testing, and the subsequent practical application of these findings to constructions, nowadays referred to as geotechnical structures [1].

From the point of view of water structures, after the breach of the Bílá Desná dam in 1916, the construction of bulk dams were resumed, especially in the Zlín region, e.g. on the Fryštátské stream.

However, a much more significant application of soil mechanics occurred in connection with the design and construction of the highway in the Czech Republic: Prague – Zlín – the Slovak border with a total length of 397 km. See the government regulation of 23 December 1938. In an attempt to have the highway in operation within 4 years, matters were entrusted to a newly created general directorate of highway construction, and scientific institutes and professional associations of all possible types related to the construction of the highway were also brought into cooperation by this directorate. For example, the Director General requested cooperation with the State Institute of Geology and with Professors of Geology at universities. Prof. Kettner volunteered to conduct a survey for the Prague circuit and parts of the track to Sázava. From the point of view of soil mechanics and earth structures, the cooperation of the State Hydrological and Hydrotechnical Institute was requested, and this was where Ing. Dr. A. Myslivec developed a detailed plan for examining the soil and utilizing the results of laboratory tests. The details of the development of the task are evidenced by the fact that at the end of August 1939, 7 field laboratories were already in operation, each for a section of 40–50 km and with the task of:

a) Determining the composition and properties of soils – in the base of embankments, in cuts and embankment material using index tests.

b) Determining the level of ground/underground water and the aquifer.

c) Controlling earthworks, especially the compaction of embankments.

d) Observing and measuring completed earthworks.

The schedule went into such details as the number of probes, the number of samples and their frequency, and respectively with an estimation of the time required (e.g. for a 5 km section 3–6 weeks).

Undisturbed soil samples were transported to the Prague laboratory for compressibility, shear strength and permeability tests. “The result of the laboratory’s activity was a report in which the slopes in the embankments and cuts, the method of compacting the embankments, various safety measures, especially against settlement, sliding, the harmful effects of frost, etc. are proposed,” as stated in the Special Print from the journal of the Association of Engineers “Technický obzor” [2].

Reading the entire printout it is worth paying attention to, from the point of view of the logic of the procedure, the speed and personal responsibility for partial decisions and steps in solving a demanding technical task, in this case the realization of 397 km of highway (including the Prague ring road) from the initial start of its commissioning (in unimaginable times for us today), in only 4 years. For this reason could then Prime Minister Ing. Alois Eliáš state in this publication that at the end of August 1939 the project for 200 km was completed and 77 km more of this highway was already under construction and preparation. However, the 2nd World War meant that all work was interrupted and also tragically PM A. Eliáš was executed.

During the 1960s, construction activity returned, both in the form of earth and rockfill dams, highways, but also earth structures of environmental engineering such as landfills, tailing dams, and spoil heaps. At the same time, laboratory instrumentation was beginning to be improved, enabling the implementation of more demanding laboratory tests, especially of mechanical and physical properties.

2. Theoretical knowledge and experience

The first decades of the conferences on Foundation Engineering were focused on the theoretical area relating to the principle of effective stresses, and thus on the measurement of pore pressures in the framework of triaxial tests, in accordance with the findings of Bishop and Skempton [3, 4], including the determination of pore pressure coefficients for the subsequent evaluation of pore pressures in earth structures due to changes in stresses. After emphasizing the importance of different stress paths [5], which are typical for individual geotechnical structures, triaxial tests were carried out under different stress paths, including drained triaxial tensile tests. Then subsequently also for differentiating the pore pressures of water and air in unsaturated soils [6]. Various methods of determining the residual strength of soils were verified.

From the point of view of compressibility, attention was also focused on tests with continuous loading, or tests where constant stress is maintained for a longer period of time with subsequent slow load increase, making it easier to define the stress, after any exceeding of which soil deformation increases again [7]. The deformation characteristics determined using the triaxial test clearly help to define these characteristics under drained and undrained conditions.

The filtration properties, especially of low permeable clays, were tested in a triaxial with back pressure to eliminate air in the pores. The measurement also focused on extremely low permeable soils – montmorillonites/bentonites, including indirect determination using the consolidation coefficient and deformation modulus measured during an oedometric test with a very slow load increase.

In recent decades, more attention has been paid to tests with cyclic loading, including the possibility of using the propagation of seismic waves to evaluate soil properties. Scanning microscopes enable a better understanding of the importance of microstructure on the behaviour of soils.

Direct determination of mechanical-physical properties in the field appears rather cyclically, for example shear tests on a block of semi-broken bedrock, but exploratory field methods are still not as common in the Czech Republic as they are abroad.

3. Earth structures in transport engineering

Attention in the Czech Republic is mostly focused on road and railway constructions. Less attention has been paid to airports and ports, even though the findings from the construction of airports on the seabed (e.g. the case of Osaka) brought a lot of new knowledge and experience.

The return to the construction of highways and the subsequent reconstruction of the railway network could thus already respect the ultimate limit states and serviceability limit states under short-term/undrained and long-term/drained conditions and predict initial and total settlement, respectively short-term stability (mostly decisive for the stability of embankments) and long-term stability (mostly decisive for the stability of cuts). Related to this is the evaluation of the speed of consolidation of the embankment subsoil, including the possibilities of its acceleration, where great attention is paid to the theory and application of vertical geodrains [8].

The application of various geosynthetics at the end of the 1970s, capable of performing various functions, brought many possibilities. The reinforcement function is thus used to increase the steepness of embankment slopes, and for the possibility of using less obviously suitable soils. Attention focused both on defining the properties of reinforcing geosynthetics, where creep plays an important role, and also on calculation methods to include the significant tensile strength of geosynthetics in slope stability calculations [9]. Reinforcing geosynthetics also enable the design of spreading platforms for the foundation of embankments even on highly compressible subsoil.

The need for greater use of even less suitable soils leads to the development of methods for their improvement (e.g., Van Impe [10]), where lime stabilization for clayey soils plays an important role. A smaller volume of lime improves workability, and better compaction of even moist soils; a larger percentage of lime then also brings long-term strength improvement. However, it is necessary to control the possibility of the mineral ettringite occurrence, which can cause subsequent swelling.

From the point of view of monitoring the execution of earthworks, the control of compaction using rollers marked as CCC – continuous compaction control is of great benefit, when the response sensors of the compacted subsoil can be used to assess the state of surface compaction, and thus not only obtain information about the optimal number of roller passes, but also ensure a more even surface compaction (and thus the deformation) of the earth's plains (e.g. Brand and Kopf [11]).

4. Earth structures in hydro engineering

Earth structures in water engineering differ mainly from the point of view of the frequency of changes in the level of retained water. The selection of various design situations and the verification of limit states for them is therefore one of the basic prerequisites for a successful design and safety operation [12].

For large embankment dams, we can speak of the relative constancy of this level, and thus also of smaller fluctuations in the seepage curve and associated pore pressures. Since the 1970s, increased attention has been paid to the failure of large rockfill dams with clay core caused by hydraulic seepage along a preferential path, which is most often a tensile crack. In this way, the probability of the occurrence of tensile cracks is monitored, which can be caused not only by uneven deformation, but also by hydraulic fracturing. Attention is thus focused on tensile strength, elongation at break, both under undrained and drained conditions [8]. This is not only for the needs of numerical modelling of stress changes in the body of the dam, but also for the subsequent assessment of the probability of the occurrence of a crack. If a crack should occur, two aspects are monitored, the swelling ability aimed at healing the crack, or sensitivity to erosion, where dispersive soils in particular are extremely dangerous from this perspective. The final design of the transverse profile is therefore more influenced by the above-mentioned aspects than simply by the stability of the slope.

In the last two decades, attention has been more focused on historical pond dams in connection with floods, generally with the need for their reconstruction to meet new conditions, caused primarily by a more significant load on their crown than in the Middle Ages and thus also the contact of the old wooden foundations outlet with the surrounding soil during this load. The floods have shown that a greater number of failures can be attributed to the surface erosion when the crown of the dam has overflowed. At the same time, the probability of overtopping is much higher where the dams are located close to each other, so that the additional wave from the ruptured upper dam will cause a domino effect of failure for the lower ones as well. Considering the high number of historical dams in the Czech Republic, about 25 000 in all, this risk is relatively high, and therefore it is necessary to assess the safety of dams not only individually, but also in relation to other dams in the same basin.

Similar problems of dam failures have drawn attention to flood protection levees along rivers.

5. Earth structures in environmental engineering

Spoil heaps composed from tertiary clays which overlay brown coal seams in northern Bohemia are the focus of attention for practically the entire period of the Foundation Engineering Brno conferences. First this was from the point of view of the stability of these spoil heaps (including the slopes of surface mines), but today it involves more a looking at the possibility of usage of their surface for new construction. Attention was focused not only on measuring the properties and change of excavated clay lumps character, typically from the rockfill up to soft clay, when the slope of the spoil heap could be very steep at the beginning and extremely gentle with time. Care was given to the deformation and settlement of high spoil heaps, especially in the case when the transport infrastructure was situated on their surface, as in the case of the Ervěnice Corridor [8]. Today, these experiences are also used when new structures are founded on the surface of spoil heaps, but failures are also associated with larger interventions into the spoil heap body, e.g. for new communication cuts.

Attention to the safe construction of municipal waste landfills began in the early 1990s, both from the point of view of their stability and deformation, and also from the angle of the safe design of the sealing system in relation to potential contamination of the ground. Today, practically every district has a safe landfill, and the number of new ones is significantly reduced.

Tailing dams were at the centre of attention in the very first decades, whether they were tailings for ash or residues after ore treatment. Now the emphasis is on their maintenance, or about modifications to a more environmentally favourable state – especially for tailings from uranium ore processing plants.

6. Earth structures and current trends

Over time, there is an observable tendency towards the realization of higher earth structures, communication embankments, cuts, dams, landfills and thus a greater transition from the use of analytical calculation methods to numerical ones (e.g., Potts and Zdravkovič [13]). When applying more general constitutive models than elastic or plastic ones, the requirements for tests under more general stress paths simultaneously increase.

The transition to European standards – Eurocodes – puts more emphasis on the verification of all potential limit states under all conceivable design situations. This means also a greater link between the complexity of the structure and the complexity of the rock environment, and the design approach applied to verify the limit states.

The application of the principle of sustainable construction accepts the principle that a technical solution is a necessary but not a sufficient condition. In accordance with this principle, increasing attention is being paid to saving energy (CO_2 footprint), land (reducing land use), reducing the consumption of natural aggregates and replacing them with alternatives [14].

The emphasis on digitization is primarily connected with the application of the BIM principle – Building Information Modelling. Here, the connected 3D model of the structure itself (superstructure) and the bedrock (substructure) should be considered as the basis. The BIM model has been gradually refined for the individual phases of construction design and geotechnical investigation, which significantly contributes to the cooperation of construction process partners in finding the optimal solution [14].

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